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Cecil Gray Johnson

A STUDY OF WORK PERFORMANCE PHENOMENA

A THESIS

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ABSTRACT

The formulation of a theoretical mathematical model to describe the characteristics of work performance phenomena is the objective of this investigation. This study has been conducted to carefully coordinate and perhaps complement the work done previously in this field of Industrial Engineering at the Georgia Institute of Technology.

Recent investigations in this area have been largely confined to detailed studies of a few operators in one plant of one industry. From the very beginning of this study, one of the basic objectives has been to extend the scope to a more comprehensive area. This has been accomplished to a limited degree.

Data for this investigation were collected from two companies with several plants located over a geographical region of the United States. These data were initially taken by trained observers in the Industrial Engineering Departments of the respective companies. The data used were carefully selected in order to obtain as representative a sample as practical. These data were analyzed by conventional statistical rules.

The results reject the null hypothesis that the characteristics of the work performance curve follow the normal distribution curve. The results show the curve to be significantly

positively skewed and significantly more peaked than normal. It also indicates a positive correlation between the statistical measures of mean and standard deviation, a negative correlation between the statistical measures of mean and skew, and a negative correlation between mean and kurtosis. It shows a strong positive correlation between skew and kurtosis. These results are generally complementary to previous work in this field at the Georgia Institute of Technology.

Future investigators in this area should be careful to avoid the severe limitations of available valid data. The use of the electronic digital computer was very helpful in this study to overcome the handicap of making arduous statistical computations.

A primary recommendation for continuing this work centers around the hypothesis that the variations in a worker's performance conform to the compounded effects of the basic laws of motion plus a constant chance cause system. It is further recommended that this hypothesis be tested under controlled laboratory conditions, taking care to study the more sensitive independent variables of force and distance and giving less attention to the dependent variable of time.

CHAPTER I

INTRODUCTION

An understanding of the performance characteristics of people in work situations is the objective of this investigation. Knowledge of work activities stem from an understanding of the phenomena of work as related to one of its most important factors, the human being.

From a perspective, it seems desirable that some of the more obvious qualitative aspects of the investigation problem be reviewed.

By comparison with simple physical and mathematical scales people have very definite limitations on work that can be performed. The simple physical capacities of man have certain definite highs and lows. This has particular reference to man when performing mechanistic acts such as lifting weights, exerting forces through a series of levers and linkages, so that in such cases prediction of outcome is reliable. By present methods, people's actions become less and less predictable even in localized and controlled conditions when the motion patterns or the thought process, coupled with the motion patterns, become more complicated. However, this investigation has limited itself to performances that can roughly be classified on the simpler side of the difficulty scale with habituation from repetitiveness a prime factor to be considered.

The capacities of people vary between individuals, but the group exhibits certain limits beyond which no individual can perform. Championship performances of athletes are good examples of individual performance at the maximum end of the scale.

The capacity of any individual or any group changes on a time scale. One obvious observation is that individual capacities increase or decrease as each individual grows older. Also, very significantly associated with the time scale is the effect of habituation. The individual's performance of any work for a fairly short time interval is affected by previous work patterns. In addition, an individual's performance of any work for a discrete time interval is affected by an inner drive or compulsion commonly classified as motivation. Negatively, work performance for a discrete time interval is affected by an accumulative retarding force generally described as fatigue. There may be other qualitative considerations. Despite the complications of the investigation area, there are some good indications that the human being in a functional work environment will exhibit certain patterns of behavior. Without reference to experimental evidence, it is reasonable to expect that a fairly consistently proportioned human body that is influenced by a repetitive type environment will perform in a repetitive manner. It also seems reasonable to expect that the repetitive pattern will have some significant variations because the pattern is affected by several significant causes.

A considerable amount of work has been done in investigating this area, but many of the results are confusing and inconclusive. At the observation stage of this investigation, it might be beneficial to point out what seems to have hindered progress in learning more about work activity.

The exploratory work of a few individual contributors such as Taylor and Gilbreth has been overemphasized. Admittedly, their work sharply increased either the knowledge or awareness of the problem, but much of the work in recent years has concerned itself with reworking their basic ideas. Without attempting to name the numerous contributors in the last few years or to discredit their results which in many cases are excellent, it is generally agreed that the knowledge in this area is very inadequate. In order not to labor this point, it seems best to move into a more specific area.

In the systematic acquisition of knowledge, it is a common practice to observe, hypothesize, experiment and conclude by induction. A cursory investigation of the work done has been mostly in the observation stage. From these observations conclusions have been formed and in many cases applied. This practice has had some success but also some limitations in applications and perhaps negative results. To clear up and understand these phenomena, it is logical that one's observations and hypotheses be reexamined and followed by suitable experiments before any attempt is made to generalize results.

A general axiom of the scientific method concerns itself with the quantification of data. The work so far in this field shows a significant lack of quantitative experiment.

Another common procedure that is followed in scientific investigations is to define in a qualitative manner the factors or sub-areas contained in the whole investigation problem. Then by systematic rigorous treatment each of the basic factors, areas, or both are analyzed, evaluated, and presented in such a form that future investigations in the field need only to recognize or accept the results. Fragmentary and nonconclusive work presented in a pseudo-scientific manner might well detract from the potential investigation and create an illusion of completeness that would tend to hide the true causative effects.

The nature of this investigation and evaluation will be concerned first with the characteristics of the individual's repetitiveness; and, secondly, how this individual repetitiveness can be accumulated and evaluated for a number of individuals into a typical characteristic pattern.

A summary of the literature review might be appropriately interjected at this point. The order of this summary will be in rough chronological classifications.

CHAPTER II

REVIEW OF THE LITERATURE

Historically the basic problem of how much work or activity an individual or group should, can, or will perform in a given time period is as old as work activity. This period of time extends itself up to almost the twentieth century. From the standpoint of specific accomplishments, there is little recorded except of a general nature for this period of time.

With the advent of industrialization and the concentration of work activity, the old problem of work became more accentuated. At the same time an awareness of the scientific method brought about a dramatic appearance of a certain intensity of thinking toward work performance. This era, which was known as the Taylor-Gilbreth period, was highly formulative in developing certain concepts toward measuring and evaluating work as well as investigations into the details of composition of work. Despite the creative contributions of this period, the true causative forces concerning this subject were not discovered or developed. The primary contribution of this period was application of the scientific approach to the problem plus an interest and awareness that continues to have a profound stimulating effect.

The second twenty years of the twentieth century do not reveal any noteworthy developments in work performance study. Actually the practitioners of this period resorted to a mechanical application of strict formula application that can be shown to actually be a misinterpretation of the original concepts.

The following ten years show a shift to some work of a more positive nature. This work was closer to an extension of the work of the Taylor-Gilbreth era. This type of study is best recorded and typified by the work of Barnes, Maynard-Lowry-Stegmarten, Presgrave, Carroll. Perhaps this work is noteworthy because of its positive nature toward application.

Closely associated and overlapping the previous period comes a change in the developmental work highlighted by the critical analysis of work measurement by Gomberg (1). This writer has represented an interesting and informative argument that is particularly orientated from labor's point of view. Although it is critical and analytical in nature, his ideas serve as a useful and forceful reminder that the knowledge in this area of work performance is inadequate. This treatment of this analysis is also noteworthy in that it specifically points to some of the weak areas instead of treating the subject in generalities. After critical treatment of time study, Gomberg has the following comment to be made about the inaccuracies of work measurement:

> The range of accuracy of time study technique compares favorably with those of other fields of engineering,

but greater accuracy is required in this field than elsewhere. Writing some time ago in the Industrial Engineer, I put the case this way:

> The criterion of workability in industrial engineering is much more difficult to attain than in the physical branches of the profession despite similar levels of accuracy. For example, let us compare the accuracy of setting a time study standard in industrial engineering with the accuracy of determining stresses in beams (a problem from the field of civil engineering). . . . Both techniques compare favorably as to relative accuracy, but there is a wide discrepancy as to criterion workability.
>
> The civil engineer guarantees the workability of the bridge he designs by multiplying his results in important designs . . . by a safety factor in the neighborhood of twelve. Can you imagine what would happen if the industrial engineer attempted to use a safety factor of two, not twelve. . . .(?)[1]

The work of Davidson (2) is also noteworthy because of its analytical nature and also because his point of view and background are that of the academic and scientific researcher. In the foreword of Davidson's discussion of this subject Korn summarizes as follows:

> Advances in the profession are often misinterpreted. Concepts, ideologies, systems, methodologies, etc., are accepted, or rejected, as the case may be, because of enthusiasm, because of fears, or any number of emotional causes. Obviously, the advances in an applied science such as industrial engineering cannot be dealt with on an emotional basis. To accept, defer, or reject any one small phase, or the practice of industrial engineering as a whole, one must base one's decision upon quantitative, rather than qualitative, judgment.
>
> We are cautious to impress the reader that while much of the problem solving activity in this field proceeds in fact to a sub-scientific level, the profession of industrial engineering must finally rest upon the application of scientific knowledge. The verification and validation of industrial engineering theories, systems, methodologies, etc., fall into the

> province of the industrial engineer-scientist. The approach to such validation may well be similar to the approach of the researcher to problems in the basic sciences.

From this introduction, Davidson (3) proceeds to examine the previous work and particularly the constant chance cause system that Gomberg has presented. He further tentatively proposes the following concepts:

1) Certain observable variations in performance-time phenomena might be considered as though they were the result of a "systematic variable chance cause system." Daily work curves, for example, might be partially explained by such a concept.

2) Certain observable variations in performance-time phenomena might be considered as though they were the result of a "random variable chance cause system operating within measurable finite limits."

3) Some observable variations might best be explained as resulting from a "composite" system.

4) It is possible that over some rather definite, and determinable, time span the total results of variable chance cause systems could be regarded as though they were the result of a "constant chance cause system" in such a way that the results from different periods having the same time span would satisfy practical tests of homogeneity.

Another significant speculation that Davidson (4) makes is as follows:

> We do know however, that there has not yet been a convincing proof that scientific methodologies for the determination of time standards and forecasts are impossible or that, if possible, they must be modeled after the concepts and techniques of statistical quality control.

Davidson examines some of Barnes' work and concludes that the performance times do not constitute a normal distribution.

Davidson also examines some common predetermined time systems and concludes that if one of the systems is accurate, the other two cannot be. This investigation is particularly aimed at the validity of additive portions of synthetic data. Stated differently, are portions of a work cycle independent of the overall cycle?

Concurrent and subsequent to Gomberg's and Davidson's work, a series of studies have been conducted at the Georgia Institute of Technology under the direction of Dr. Robert N. Lehrer and Dr. Joseph J. Moder primarily in the form of work for Master of Science theses. The work covered in this area is particularly noteworthy because it has attempted to answer in a positive manner the questions that Gomberg and Davidson have asked, and also to extend the general knowledge in this field. A summary of the results can best be followed by a chronological summary of this work.

Lind's (5) thesis represents the first of a series of investigations made concerning the nature of work performance times.

The objectives of this particular thesis were summarized by Lind as follows:

(1) Do operators follow any pattern of performance or work curve throughout the day?

(2) Do unadjusted performance times tend toward any formal distribution or could they be made to form any model?

(3) Are operator's cycle times statistically stable?

(4) What is the relationship of variation within a period to the variation between periods?

The general procedure was to take 3200 observations of a short cycle, manually controlled assembly operation with a decimal minute stop watch. These observations were taken from nineteen different operators scattered over three shifts. These data were essentially treated by statistical means. The results from this analysis were summarized by Lind as follows:

(1) The operators on this operation did not follow any particular work curve.

(2) The unadjusted performance times tend to form a positively skewed distribution.

(3) The performance times of sixteen out of nineteen operators were not statistically stable.

(4) The variation within a period was significantly greater than the variation between periods.

(5) Stop watch performance time data do not give sufficient information to separate chance cause from assignable causes of variation.

In conclusion, Lind recommended that a similar study be made using high speed motion pictures as the data taking medium to facilitate the analysis of the variations.

The study made by Taft (6) followed Lind's recommendations. Motion pictures were used as the technique to record and analyze the data.

Taft's efforts were directed towards answering questions concerning the effect of variables on the cycle time distributions.

Taft's results were summarized as follows:

1. The individual operator modified cycle time distributions with variables included tend to be positively skewed.

2. The shift distributions with variables included and variables excluded are positively skewed.

3. The distributions of all shifts combined with variables included and variables excluded are positively skewed.

4. The modified cycle time distribution, with variables included and variables excluded, approximate a straight line relationship, when the log of the cycle time was plotted on probability paper; thus the distributions can be approximated by a log normal curve.

5. Variables selected and eliminated within the work cycle did not significantly alter the characteristics of the modified cycle time distribution.

Taft recommended further and perhaps more detailed work using motion pictures to aid the analyst.

Essentially McLeod's (7) study concerned itself with control chart analysis apolied to motion picture data of the Scripto Project. The assignable causes of variation previously identified by micromotion analysis of the operation were then removed and new control charts were plotted using three-sigma control limits as the criterion for stability.

The results from this analysis were summarized as follows:

> Evaluation of the significant changes appearing in the latter charts presented inconclusive evidence that the removal of the assignable causes of variation selected significantly affects the statistical stability of cycle performance times as studied. Additional conclusions were (1) that the presence in time data of certain assignable causes of variation may or may not be indicated on control charts, (2) that work times are not unstable solely on account of the presence of these variables and, (3) that micromotion analysis fails to completely identify all factors influencing work-times for manual operations.

Further study in this direction was recommended by McLeod.

Friedman's (8) study concerned itself primarily with the characteristics of the work-time distribution curve using only the statistically stable operators from the two previous parts of the Scripto Project (Lind (5) and Taft (6)). As stated by Friedman, his results are as follows:

> In view of the experimental situation, it seems reasonable to conclude that there is a theoretical work-time distribution which typifies work-time phenomena for this type of activity. This theoretical work-time distribution appears to have the following characteristics:
>
> 1. It differs significantly from the Normal Curve.
> 2. It is positively skewed.
> 3. Its peakedness is greater than that of the Normal Curve.
> 4. It can be reasonably approximated by a Pearson Type III Curve.

Friedman pointed out the limitations of this study by noting the size of the samples on individual studies, the criteria of statistical stability, the number of distributions analyzed, the short cycle normally controlled jobs, the apparently highly motivated operators, and the instrumentation employed.

The recommendations for future study were that another motion picture of the same operation be taken. From the data obtained, tests for stability would be made, and using only stable distributions, the hypothesis that work-time distributions of statistically stable operators can be typified by the Pearson Type III Curve should be further tested.

The analysis made by Summers (9) concerned itself primarily with a statistical examination of the data previously collected on the Scripto Project to determine if any relationships existed between cycle time stability and the characteristics of the work-time distribution.

Within the limitations of his study, the following conclusions were set forth:

1. There is an indication that the removal of assignable causes of variation as performed in Study C, will tend to increase the level of stability of an operator's cycle times.

2. For an operation of the type studied, the theoretical work-time distribution is positively skewed . . . The standard deviations for both skewness and peakedness values decreased markedly when cycles containing variables were removed from the data (Study C).

3. The Normal Curve does not typify the work-time distribution for this type of operation. When considering all operators, the Log-Normal and Pearson Type III Curves seem to fit the distributions equally well.

4. The results indicate that cycle time stability does not affect the mean time, skewness or peakedness of the distribution significantly.

5. Stability does affect the dispersion of the total distribution. It also affects the dispersion of the sub-distributions of cycles within periods. As stability increases, total variance and "within periods variance" decrease.

6. There is little relationship between stability and goodness of fit for the Normal, Log-Normal, and Pearson Type III Curves.

7. There is evidence that as operators become more

experienced, their cycle times are likely to become more stable. However, when the cycles containing variables are eliminated, this correlation is no longer apparent.

8. From the analysis of the scatter diagrams, it seems reasonable to conclude that the typical work-time distribution for a short cycle operation will have both a constant skewness and a constant peakedness when the assignable causes of variation are eliminated. This result suggests that the typical curve is not necessarily one of those tested, but that it may be another curve with constant skewness and peakedness, and that the variance of this curve will be the only independent parameter which will influence its shape.

Summers' thesis recommends an extension of this work to include a longer and more comprehensive motion picture study, together with a more detailed and precise classification of assignable causes of variation. As an improved analysis technique, multiple correlation is recommended.

Green's (10) thesis concerned itself primarily with an analysis of the characteristics of the elemental times as compared to the characteristics of the work cycle times. The data used were the Scripto data collected in 1951. The summarized results and conclusions are as follows:

1. The characteristics of the element-time distributions and work-time distributions of the cycle of which the elements are a part were similar.

2. Of the curves tested, the Log Normal and Pearson Type III curves were the curves of best fit to the experimental distributions, but the theoretical element-time distribution curve may not be one of those tested.

3. There was evidence of independency among the elements of this operation.

4. The effect of leveling the element times to compensate for the difference in the level of operator performance during the shift was to reduce the amount of peakedness and skewness of the distribution.

Green pointed out the limitations of the study by noting the small and somewhat restricted sample used (one operator, one method). He recommended that further work be done on this subject but in a more rigorous manner.

Perkins' (11) thesis used the micromotion data previously collected on the Scripto Project to investigate the relationships between elements in the work cycle. The results were as follows:

> It was found that there was evidence of correlation among the elements of the work cycle for both the five and two element breakdowns. In addition, the following conclusions were drawn on the basis of the test results:
>
> 1. There was an indication that the degree of correlation among the elements of a cycle does not remain constant for the same operator during the work shift.
>
> 2. The nature and extent of correlation among the elements of a work cycle from period to period appeared to depend on the operator.
>
> 3. It appeared that in those shots where the degree of correlation was found to be the highest, there was a concentration of variables.
>
> 4. There was an indication that the degree of correlation among the elements of the five element breakdown was decreased by combining these elements into a two element breakdown of the operation.
>
> 5. The grouping process did not decrease the degree of correlation among the elements to the same extent for the same operator or data for different shots.

6. The stable and unstable operators exhibited similar characteristics in regard to the degree and extent of correlation among the elements of the cycle.

Perkins recommended that a further analysis be made of this data.

Roger's (12) study concerned itself with the results of work distributions taken with significantly larger sample sizes (larger than 500) in the Scripto plant. The operation chosen was similar to the ones described in previous studies in this plant. The data were taken with a micromotion camera and a multi-minute timer designed and constructed particularly for work of this type. These data were analyzed by separating delay time from work time and the statistical characteristics of each classification were compared with previous work of this type. Rogers stated his results as follows:

> The results substantiated previous work in the analysis of work-time distributions as the work time distributions obtained in this study were all positively skewed and more peaked than the normal curve.
>
> The mean, variance, and measure of skewness and peakedness decreased when cycles containing internal delays were omitted from the study.
>
> External delays exceeded internal delays in both number and mean length.
>
> Within the limitation of the small sample sizes of delays obtained, the frequency distributions of delay times did not differ significantly in measures of skewness and peakedness from the normal curve.
>
> Work-time distribution means for individual operators varied significantly from hour to hour in the observation period, but the standard deviation of the individual operators did not show significant variation.

> Further investigation should be made concerning their relationships in order to more properly determine the salient features of a pure work time distribution.

The results from the intensive and detailed work done on the Scripto Project are noteworthy from an informational point of view, but perhaps the method of collecting and treating the data by quantitative and statistical methods is more important.

However, regardless of the validity of the information from these studies the investigator must ask the following question: If detailed studies of a very small number of selected operators in one plant give certain results, can it be induced that these conclusions pertaining to work performance phenomena are applicable to all workers or even a population of workers engaged in repetitive manufacturing operations?

To answer this question in the spirit of scientific inquiry, further and more extensive investigations must be made to test these localized results.

The asking of this question has led to the objective of this study. However, in extending this work in a meaningful manner, attention has been paid to following a pattern of investigation that will complement and perhaps extend the previous work.

CHAPTER III

OBJECTIVES

The objective of this study is to extend in a more general manner the investigation of work performance phenomena.

Recent specific investigations at the Georgia Institute of Technology have concerned themselves with collecting and evaluating data that were based on a specific situation, namely, the Scripto plant. Secondly, a relatively small sample of operators were taken in this one plant. Thirdly, the data that were taken were reasonably well detailed, and were therefore readily adaptable for measuring, evaluating, and perhaps drawing of conclusions of a localized nature.

In this study the objective has been to collect and evaluate sample work performance data from several plants scattered over a wide geographical area. To further enhance the sample and give it an aspect of randomness, data from a number of operators on different jobs at different times have been used.

The problem is to investigate the characteristics of the work performance pattern in repetitive activity situations, and to evaluate the results in such a manner as to determine the characteristic pattern both from a qualitative and quantitative viewpoint.

To give this investigation a specific objective that would complement previous work, the following null hypothesis was made:

> The element time distribution characteristics do not vary significantly from the statistical characteristics of a normal distribution curve.

CHAPTER IV

PROCEDURE

The nature of the problem area has been generally described in the introductory chapter. However, certain qualitative characteristics that seem significant to the area under study are presented prior to the detailed procedure.

The population from which the sample is to be taken is as large as human activity. In this population, there are significant variations between individuals and also variations within an individual. This study will be as concerned with the former as much as the latter.

At this stage, the researcher is confronted with an almost unlimited supply of available subjects for study. Primarily, because of economic considerations both in collecting and evaluating the samples, this study will confine itself to selecting and evaluating studies that have been previously made.

The instrumentation in this area of investigation has been developed to an extent that allows the researcher a choice of devices and methods. These devices and methods have limitations associated with their inherent errors, but again from economic expediency it has seemed best to use instruments already developed. The errors in these instruments are cumbersome to manage but not prohibitive to use.

It seems pertinent to point out that measurements in this area of study are somewhat unique in that both the observer and the observed are likely to compound the typically hard to manage human error.

By the combination of injecting the use of standard statistical evaluation and by using the digital computer for rapid and economical calculations, some of the procedural limitations just mentioned can be partially offset.

The data used can now be described as follows:

The data are in the form of stop-watch time studies. The recording device used is the decimal minute stop watch. Some information is available on the accuracy of the instrumentation. Firstly, the watches are certified for operational accuracy by the manufacturer as an inspection routine. Secondly, the watches are purchased, maintained, and used by personnel trained in the care and use of the instrument. In this training, it is customary to periodically check the accuracy of the timing device against some other accurate timing device, preferably not a spring-wound wrist watch. Also, in a considerable portion of the data (approximately one-half) the elapsed time of the observed period is double-checked by means of times taken from a wrist watch or an electric driven clock. This process is not so much a question of scientific instrumentation but a reflection of the personnel making the observation and at least some practical considerations of accuracy. Another consideration of instrument accuracy is the comparison of data taken with similar data. It is the practice to retake the data, checking the instrument and other causes if the error is apparent. Again this is not offered as proof of correctness of the stop watches but indicative of the reasonable care and use that is employed by the personnel.

If all human activity is the universe about which one wishes to generalize, then the choice of a sample from repetitive manufacturing is somewhat restrictive. The sampling is further restricted because some of the groups who do collect and record samples of this kind of data do not make the data available for investigations of this type. Despite these limitations, however, the groups chosen do not fall into any separate or peculiar categories. They were generally chosen to represent a limited cross-section of manually controlled manufacturing activities. This is more a matter of expediency than design, but again there seems to be no particular reason even in a controlled design to not use somewhat the same choices.

The individuals chosen within the groups have been randomly chosen after the data were recorded and filed. However, in choosing the individuals to be studied, it has been common practice to choose the operator whose production and earnings were closest to the average or median value. Since this study is concerned with an investigation of the typical central tendencies, the choice of sampling operators who demonstrate typical central tendencies presents no difficulty. It does seem significant to point out this prejudice in the data collection.

Geographically, the data were assembled from individuals that had a fairly wide dispersion in the Southeastern portion of the United States. The groups from which the data were collected were predominantly composed of white women but there were also some men. No selected choice of groups such as according to skill, education or training was made.

The cycles were divided into elements that ranged from 0.03332 to 0.4727 minutes with a mean of 0.1522.

The observers in every case were experienced time study observers with an approximate time in their positions of from two to five years. These observers gave every indication of being of a typical pattern and their competence defined by occupational title. It seems particularly significant to note that these observers were also of a random nature. Another point to note that is comparatively significant is the exclusion of the time study rating error of the observer. This investigation is limited only by his observing the ending points of the elements and recording their values as read from the stop watch. This gives the fortunate exclusion of the subjective rating of the data.

The data used were specifically collected from two companies who had branch plants. The results of this data from these two companies can then be compared to the data previously taken from the Scripto Company. The choice of these two companies has in many respects been dependent upon consideration of available data, and manually controlled repetitive jobs with a fairly wide geographical location. Although this does not represent an ideal sample of all human behavior, it does give a practical working sample.

The elemental times expressed in hundredths of a minute were each plotted on time-frequency histograms. The time-frequency for each element was solved for the statistical characteristics of mean, range, standard deviation, mode, median, skew, and kurtosis. A sample of this histogram, together with the statistical results, are tabulated in Figure 1 of the Appendix. Also on these histograms were tabulated other descriptions concerning the company, department, and the operator. A comprehensive tabulation of the statistical results of all the elemental times has been included in the Appendix.

These results were then plotted in graphic form as shown in Figure 2 through Figure 5 of the Appendix. By using the relationships indicated in the graphs, linear correlations were calculated and the results of these calculations are shown in Table 8 and Table 9.

CHAPTER V

RESULTS AND CONCLUSIONS

Generally, the results are complementary to the work previously done on the Scripto Project. The time-frequencies were found to be significantly positively skewed and significantly more peaked than the Normal Curve. By examining the detailed contents of Table 1 through Table 7 in the Appendix, the tabulated statistics show that the individual time-frequencies are consistent in these characteristics. The results shown in these tables were averaged for the studies and the average mean was found to be 0.1522 minutes, the average standard deviation was found to be 0.0247 minutes, the average skew was found to be 1.52 as compared to 0.0 for the Normal Curve, and the average kurtosis was found to be 7.73 as compared to 3.0 for the Normal Curve.

On the basis of these results, the proposed null hypothesis, namely, that the element time distribution characteristics do not vary significantly from the statistical characteristics of a normal distribution curve, is rejected.

This completes the basic objective of extending the specific results from the Scripto Project to results that are more general.

Some further interesting results from this study are shown in Table 8 and Table 9 of the Appendix. By comparing the individual study statistical characteristics by linear correlation, it was shown that there existed a positive relationship between mean and standard deviation, a weak negative relationship between mean and skew, a weak negative relationship between mean and kurtosis, and a strong positive relationship between skew and kurtosis.

These results suggested the detailed plotting of the graphs shown in Figure 2 through Figure 5 of the Appendix. From these graphs, it becomes evident by examination that curvilinear relationships might be more appropriate than linear relationships.

Conclusions that can be drawn from these results should be interpreted as promising observations. Not only did the results suggest the rejection of the Normal Curve as the model, but more significantly, the results suggested that the shape of the curve would change as the mean time changed. The curvilinear relationships further suggested that the mathematical model involving time as a dependent variable must be something other than a linear relationship.

CHAPTER VI

RECOMMENDATIONS

At best, these conclusions can be taken only as an observation. Therefore, from these results it seems appropriate that a hypothesis be proposed. It is intended, of course, that this hypothesis be followed in subsequent work by a suitably designed experiment. The general nature of this experiment will also be proposed.

This hypothesis will concern itself with suggesting the variables that may be causing the dependent variations of observed times. The first suggestion is that time is a dependent variable that results from one or more independent variables. This would also seem true of production or production rate.

Next, it can be observed that the human in a work or activity situation will exhibit one or more of four general conditions or activity or inactivity.

1. The body is relaxed and at rest and asleep.

2. The body is inactive but not relaxed to the point of being asleep. The general connotation of idle is appropriate.

3. The body or its members is not moving but is exerting a force upon some stationary object. This is generally described as holding.

4. The body or its members is in motion. By analyzing these motions, it is found that essentially these motions are composed of a series of a number of smaller motions that have frequent starts and stops or abrupt changes of direction. Looking at this closer, it becomes apparent that the small and subtle changes accumulate to form a rather complex pattern if observed in its accumulated form. This accumulated pattern can be analyzed and found to be primarily accelerations with an infinite number of rates of changes.

Because of this observation, it seems appropriate that motions be described by the accepted laws of motion.

1. A body at rest remains at rest, and a body in motion continues to move at constant speed along a straight line, unless the body is acted upon in either case by an unbalanced force.

2. An unbalanced force acting on a body causes the body to accelerate in the direction of the force, and the acceleration is directly proportional to the unbalanced force and inversely proportional to the mass of the body.

3. For every action, there is an equal and opposite reaction.

Again by comparing the states that the human body is in to the laws of motion, it seems logical that one or more of the laws are applicable to any of the states of our particular body. Further observations of a work activity will show that we are primarily concerned with number four (4). If the body moves from rest to another state of rest as number four (4) implies then basic law number two (2) is appropriate to describe this phenomena. The mathematical model for this phenomena is expressed as follows:

$$a = \frac{F}{M}$$

Where a = Acceleration
F = Force
M = Mass

For the sake of explanation only, if the description is confined to linear uniformly accelerated motion patterns, then the acceleration can be further expressed as follows:

$$S = V_0 t + 1/2\ at^2$$

Where S = Distance
V_0 = Initial velocity
t = Time
a = Uniform acceleration

If it is assumed that the initial velocity is zero the simplified equation becomes:

$$S = 1/2\ at^2$$

$$a = \frac{2S}{t^2}$$

substituting in F = KMa

$$F = \frac{KM2S}{t^2}$$

$$t^2 = \frac{K'S}{F}$$

Going back to the original work activity and applying this approximate model, the time values perhaps explain themselves by the pictorial view of the mathematical model shown in Figure 6 of the Appendix.

In explanation of this model, it is noticed that for a given method even in industrial practice, the mass would essentially remain constant. If one imposes the improbable condition of a rigid constant method then the time values would approach zero as the force becomes infinitely large. Again, if force were held constant the time would vary directly as the square root of the distance. This is best viewed with the three-dimentional graph.

It seems particularly important to note that the time values are relatively insensitive to changes of either force or distance because of the exponential relationships.

This is presented as a logical and possible explanation of why the operators' performance curves are more skewed and peaked than normal. Because of the relationship of time to the independent variables of distance or method (assuming M constant) and force, it is reasonable to expect that for any given set of conditions it becomes increasingly difficult to perform the job in each subsequent time interval as t approaches zero. This would tend to explain not only the skewness and peakedness but also the different shape performance curves for different job conditions and different operators.

To further complicate this explanation is the assumption that only the simplified case of the second law of motion is applicable. This, of course, is only a simplified approximation of the mathematical model.

In conclusion, it is suggested that this theory be examined by a series of carefully controlled laboratory experiments. The hypothesis proposed is as follows:

> The theoretical characteristics of the work performance is described by a composite of Newton's laws of motion and a constant chance cause system of variation.

APPENDIX

Table 1. Plant 1A. Tabulation of Statistical Description of Elemental Frequency Distributions.

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
3	.0817	.07	.0122	.03	.0759	72	.18	3.0
4	.2178	.15	.0282	.21	.2067	72	.89	3.8
5	.2446	.16	.0276	.23	.2332	71	.74	3.5
6	.1335	.10	.0160	.11	.1061	72	1.03	4.7
7	.1221	.09	.0173	.12	.1136	71	1.05	3.8
8	.1865	.11	.0230	.17	.1775	48	.73	3.0
9	.1929	.11	.0253	.19	.1846	48	.29	2.2
10	.1819	.15	.0282	.16	.1700	48	1.80	6.6
11	.1770	.13	.0244	.17	.1788	48	1.93	7.1
12	.0674	.07	.0110	.06	.0598	96	1.05	4.3
13	.1447	.12	.0158	.13	.1375	96	1.93	10.4
14	.1822	.10	.0227	.17	.1720	36	.73	3.1
15	.1806	.08	.0181	.18	.1767	36	.68	3.1
16	.1889	.16	.0313	.17	.1767	36	1.99	7.0
17	.1833	.10	.0173	.18	.1750	36	2.05	8.0
18	.0635	.10	.0138	.06	.0559	72	2.49	11.2
19	.1493	.12	.0162	.14	.1425	72	1.69	9.5
20	.0866	.11	.0138	.08	.0787	96	1.93	10.4
21	.0815	.12	.0188	.07	.0756	96	.57	3.9
22	.2885	.16	.0231	.29	.2850	96	-.23	5.5
23	.2069	.16	.0302	.19	.1958	96	1.39	5.3

Table 1. Plant 1A. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
24	.1893	.15	.0203	.19	.1828	96	1.76	9.4
25	.1733	.26	.0330	.15	.1620	96	1.98	10.5
26	.0922	.13	.0139	.09	.0857	96	1.94	13.2
27	.1635	.14	.0262	.15	.1538	96	1.32	5.0
28	.0933	.17	.0162	.10	.0933	72	2.25	9.3
29	.1018	.10	.0204	.09	.0850	72	3.48	22.0
30	.1050	.09	.0153	.10	.0979	48	1.37	5.4
31	.1085	.13	.0202	.10	.0995	48	3.23	15.3
32	.1103	.19	.0231	.10	.1008	96	3.27	19.9
33	.1155	.11	.0208	.105	.1012	96	1.25	4.5
34	.1028	.08	.0128	.10	.0959	72	1.20	5.2
35	.1025	.06	.0108	.10	.0959	72	.82	3.6
36	.1260	.07	.0251	.12	.1169	72	5.49	40.4
37	.1415	.15	.0289	.13	.1295	72	2.01	7.1
38	.1558	.17	.0320	.14	.1460	72	.95	4.2
39	.1514	.20	.0409	.12	.1355	72	1.39	4.8
40	.1335	.21	.0345	.115	.1179	72	2.55	10.4
41	.1148	.18	.0195	.11	.1079	71	2.75	18.6
42	.1040	.12	.0190	.10	.0950	120	1.62	6.4
43	.1117	.12	.0227	.10	.1000	24	2.47	9.9

Table 1. Plant 1A. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
44	.1129	.05	.0121	.10	.1067	24	.72	2.8
45	.3150	.10	.0204	.11	.3050	24	.95	3.6
46	.1092	.07	.0119	.11	.1036	24	1.36	6.5
47	.0904	.07	.0127	.09	.0836	24	1.49	5.6
48	.1937	.08	.0204	.18	.1825	24	1.02	3.0
49	.1688	.08	.0185	.16	.1600	24	.81	2.9
50	.2467	.17	.0449	.33	.3350	24	2.59	12.0
51	.3450	.08	.0144	.33	.3375	24	.07	1.8
52	.3637	.21	.0421	.36	.3550	24	1.37	5.5
53	.1029	.21	.0377	.10	.0910	24	4.29	20.3
54	.0945	.05	.0115	.09	.0886	24	.34	2.1
55	.1121	.14	.0286	.10	.0975	24	2.36	9.0
56	.0967	.05	.0131	.10	.0914	24	-.31	2.0
57	.2742	.17	.0380	.265	.2600	24	1.09	3.7
58	.1196	.07	.0162	.11	.1120	24	.71	2.8
59	.0842	.07	.0135	.085	.0800	24	.48	3.1
60	.1688	.16	.0185	.13	.1200	24	.81	2.9
61	.1904	.17	.0377	.18	.1760	24	.95	3.5
62	.3179	.20	.0416	.34	.3050	24	1.23	5.0
63	.3317	.21	.0424	.30	.3125	24	1.86	6.7

Table 1. Plant 1A. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
64	.4370	.26	.0651	.43	.4300	24	.08	2.5
65	.0921	.13	.0268	.08	.0786	24	1.68	5.7
66	.0883	.12	.0234	.08	.0767	24	1.96	7.0
67	.2001	.13	.0224	.19	.1931	72	.83	4.1
68	.1761	.13	.0234	.18	.1700	72	.60	3.3
69	.2019	.13	.0190	.20	.1956	72	1.28	7.5
70	.1668	.13	.0204	.16	.1588	72	1.28	5.7
71	.0651	.18	.0303	.05	.0496	96	2.75	10.6
72	.0575	.14	.0185	.05	.0479	96	3.59	18.7
73	.1295	.17	.0230	.12	.1284	96	2.58	13.0
74	.1426	.22	.0308	.13	.1296	96	2.79	13.9
75	.0688	.20	.0337	.06	.0546	72	3.19	13.6
76	.0536	.10	.0141	.05	.0460	72	3.20	16.2
77	.1279	.17	.0307	.12	.1150	72	2.44	9.8
78	.1358	.15	.0244	.13	.1264	72	1.82	7.9
79	.0581	.07	.0090	.06	.0520	120	1.58	7.3
80	.1003	.10	.0141	.10	.0935	72	2.64	13.1
81	.2436	.11	.0211	.23	.2257	72	.38	3.1
82	.0996	.11	.0163	.09	.1910	96	1.93	8.6
83	.1969	.12	.0195	.19	.1870	96	1.39	5.4

Table 1. Plant 1A. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\bar{X}$	R	s	M_o	M_d	n	g_1	g_2
84	.1229	.10	.0155	.12	.1153	72	1.64	7.2
85	.1225	.13	.0287	.09	.1136	72	.39	2.3
86	.0735	.18	.0259	.07	.0638	72	3.23	16.7
87	.1342	.09	.0160	.12	.1264	48	1.39	5.2
88	.1183	.07	.0156	.11	.1100	48	.80	2.9
89	.0819	.11	.0228	.08	.0729	48	1.90	6.5
90	.2097	.12	.0199	.21	.2120	72	.55	4.0
91	.0514	.14	.0250	.04	.0413	57	1.77	6.9
92	.2131	.16	.0254	.20	.2038	48	1.46	7.4
93	.0622	.15	.0343	.04	.0450	36	1.27	4.0
94	.1863	.14	.0222	.17	.1788	96	1.02	5.1
95	.2182	.16	.0298	.20	.2096	95	.94	4.2
96	.1219	.18	.0308	.11	.1078	72	2.03	8.0
97	.2706	.29	.0504	.24	.2518	72	1.84	6.8
98	.2586	.26	.0438	.24	.2436	72	1.06	3.9
99	.2244	.15	.0338	.19	.2113	72	.68	2.5
100	.1115	.14	.0262	.10	.1000	72	2.15	7.5
101	.2510	.25	.0364	.24	.2433	72	.50	5.8
102	.2312	.08	.0292	.23	.2224	72	1.25	4.4
103	.2110	.20	.0302	.19	.2000	72	2.54	12.1

Table 2. Plant 1B. Tabulation of Statistical Description of Elemental Frequency Distributions.

Identification Number	$\bar{X}$	R	s	M_o	M_d	n	g_1	g_2
104	.0633	.10	.0096	.06	.0569	144	.86	3.9
105	.0685	.07	.0107	.07	.0628	144	.91	4.6
106	.0501	.13	.0106	.05	.0441	144	.98	4.5
107	.0947	.14	.0219	.09	.0874	72	1.79	8.2
108	.0513	.14	.0195	.04	.0404	67	1.51	4.7
109	.0647	.14	.0186	.06	.0560	72	2.90	15.7
110	.0530	.09	.0153	.05	.0420	69	1.60	5.9
111	.0536	.13	.0203	.05	.0430	70	2.44	10.1
112	.0937	.18	.0256	.09	.0864	70	1.49	7.5
113	.0452	.08	.0240	.03	.0344	64	3.69	21.5
114	.0746	.07	.0147	.07	.0680	72	.30	2.5
115	.0692	.08	.0107	.07	.0633	144	.65	4.1
116	.0587	.10	.0149	.05	.0494	144	1.70	6.7
117	.0529	.04	.0082	.05	.0470	143	.37	2.5
118	.0731	.07	.0103	.07	.0674	140	.25	3.4
119	.0614	.06	.0085	.06	.0570	36	.51	5.2
120	.0647	.05	.0083	.06	.0580	36	.96	3.9
121	.0534	.06	.0109	.05	.0470	35	1.26	5.2
122	.0894	.05	.0108	.08	.0833	34	.25	2.1
123	.0833	.05	.0097	.08	.0769	34	.26	2.0
124	.0744	.08	.0130	.07	.0680	36	1.03	5.6

Table 2. Plant 1B. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\bar{X}$	R	s	M_o	M_d	n	g_1	g_2
125	.0657	.08	.0147	.06	.0566	214	1.53	5.0
126	.0587	.07	.0117	.05	.0513	216	1.43	5.0
127	.0626	.05	.0074	.06	.0564	72	1.14	5.2
128	.0650	.09	.0283	.05	.0550	72	4.72	31.9
129	.0714	.08	.0134	.07	.0641	36	2.53	11.1
130	.0537	.07	.0111	.05	.0473	72	.81	4.0
131	.0642	.05	.0076	.06	.0580	36	1.03	5.0
132	.0803	.13	.0237	.07	.0686	71	2.13	8.2
133	.0393	.07	.0119	.03	.0318	72	1.99	7.7
134	.0926	.12	.0245	.07	.0836	72	.75	3.2
135	.0382	.03	.0192	.03	.0203	72	6.89	54.6
136	.0892	.12	.0255	.08	.0777	72	1.36	4.4
137	.0503	.11	.0190	.04	.0387	72	1.78	6.8
138	.0850	.11	.0169	.08	.0778	71	1.02	5.3
139	.0356	.10	.0134	.03	.0273	70	4.29	24.9
140	.0399	.10	.0133	.04	.0330	72	2.34	12.2
141	.0812	.10	.0176	.07	.0718	72	1.01	3.7
142	.0383	.06	.0091	.04	.0324	72	1.88	8.7
143	.0397	.03	.0055	.04	.0348	36	-.35	2.2
144	.0397	.06	.0083	.04	.0342	36	2.96	15.7

Table 2. Plant 1B. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	ε_1	ε_2
145	.0564	.05	.0136	.05	.0492	36	1.67	7.5
146	.1144	.25	.0291	.10	.1033	144	3.93	23.6
147	.1153	.15	.0237	.10	.1048	144	2.78	12.8

Table 3. Plant 1C. Tabulation of Statistical Description of Elemental Frequency Distributions.

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
2	.1361	.13	.0197	.14	.1278	72	2.25	11.8
148	.0862	.13	.0225	.08	.0757	93	2.96	12.1
149	.1189	.07	.0146	.11	.1119	72	.86	3.7
150	.0647	.07	.0103	.06	.0583	241	.59	4.3
151	.1914	.17	.0311	.18	.1797	93	1.01	4.1
152	.1949	.17	.0368	.17	.1805	117	.69	3.0
153	.1323	.14	.0254	.12	.1230	47	1.04	4.8
154	.1031	.14	.0284	.10	.0941	48	2.06	7.9
155	.1299	.20	.0300	.12	.1180	113	1.35	7.0
156	.1003	.18	.0269	.10	.0918	108	1.74	8.8
157	.1195	.10	.0184	.12	.1133	114	.55	4.1
158	.0924	.19	.0229	.09	.0838	121	1.81	7.9
159	.2982	.13	.0259	.32	.2921	49	.28	2.9
160	.3080	.25	.0491	.30	.2964	69	1.26	4.9
161	.2835	.16	.0468	.30	.2764	118	-.34	7.8
162	.1031	.09	.0137	.10	.0955	192	1.41	5.7
163	.1230	.12	.0231	.11	.1113	163	1.28	4.2
164	.0613	.06	.0113	.06	.0549	192	3.27	19.1
165	.1369	.14	.0201	.14	.1300	96	3.25	16.7
166	.1447	.16	.0226	.14	.1366	96	3.01	15.0
167	.0726	.09	.0131	.07	.0675	70	.83	5.1
168	.1976	.13	.0234	.20	.1939	71	.10	3.4

Table 3. Plant 1C. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
169	.0862	.13	.0223	.08	.0783	71	1.23	6.1
170	.1164	.10	.0304	.10	.1060	72	2.18	12.6
171	.0896	.14	.0221	.08	.0790	69	2.69	12.4
172	.1753	.10	.0174	.20	.2033	72	.89	3.4
173	.2243	.18	.0282	.16	.1563	237	1.07	3.2
174	.1575	.17	.0298	.15	.1468	133	1.25	5.5
175	.1391	.08	.0176	.13	.1300	88	1.20	5.0
176	.1717	.17	.0329	.15	.1614	91	.85	3.6
177	.1357	.18	.0379	.12	.1191	162	1.87	6.5
178	.1090	.14	.0167	.10	.1017	210	1.29	7.2
179	.0819	.18	.0242	.07	.0718	46	2.50	13.3
180	.1568	.13	.0254	.16	.1506	47	.52	3.3
181	.4257	.27	.0565	.405	.4175	44	1.20	4.9
182	.3218	.16	.0317	.33	.3175	44	.27	2.7
183	.1050	.11	.0210	.10	.0990	48	.28	2.9
184	.1675	.16	.0385	.18	.1850	45	.34	2.2
185	.4639	.19	.0523	.44	.4500	44	.92	4.8
186	.3205	.21	.0473	.30	.2994	43	1.25	4.4
187	.1305	.12	.0242	.15	.1336	55	.49	2.9
188	.1418	.17	.0298	.13	.1300	66	1.06	4.6

Table 3. Plant 1C. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\bar{X}$	R	s	M_o	M_d	n	g_1	g_2
189	.2330	.14	.0271	.25	.2293	69	.24	2.9
190	.2594	.22	.0499	.22	.2410	69	.68	2.5
191	.1445	.14	.0291	.13	.1315	69	1.08	3.7
192	.1345	.14	.0272	.125	.1258	69	1.00	4.3
193	.2786	.23	.0411	.30	.2669	69	.93	4.5
194	.3510	.32	.0471	.35	.3375	70	.78	5.3
195	.2528	.22	.0352	.24	.2450	72	.39	3.9
196	.3174	.22	.0499	.35	.3025	70	.79	3.7

Table 4. Plant 1D. Tabulation of Statistical Description of Elemental Frequency Distributions.

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
197	.1004	.10	.0142	.14	.1433	68	1.34	5.3
198	.1601	.08	.0359	.10	.0932	70	1.58	5.3
199	.1987	.17	.0321	.18	.1875	100	.69	3.2
200	.1213	.14	.0232	.11	.1108	104	1.76	6.8
201	.0857	.12	.0184	.08	.0770	163	2.08	9.7
202	.0906	.13	.0198	.085	.0818	65	1.83	7.0
203	.1249	.19	.0333	.105	.1150	101	.91	4.1
204	.0749	.18	.0322	.055	.0605	102	2.15	8.2
205	.1346	.15	.0312	.12	.1196	104	.98	3.5
206	.0617	.10	.0144	.05	.0533	108	1.65	6.9

Table 5. Plant 1E. Tabulation of Statistical Description of Elemental Frequency Distributions.

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
207	.0501	.12	.0167	.06	.0615	180	3.25	19.8
208	.1228	.12	.0208	.12	.1156	214	.57	3.2
209	.0650	.10	.0131	.06	.0587	180	1.45	6.9
210	.2223	.21	.0385	.21	.2087	142	2.20	11.6
211	.2192	.18	.0325	.20	.2080	142	.81	3.6
212	.1998	.18	.0285	.20	.1998	140	4.03	24.0
213	.1898	.19	.0217	.18	.1858	131	.29	7.2
214	.0519	.07	.0077	.05	.0458	178	2.46	14.0
216	.0475	.15	.0194	.04	.0388	232	2.36	11.6
217	.1450	.16	.0229	.14	.1378	355	2.45	16.7
218	.0797	.09	.0139	.07	.0737	72	.21	3.6
219	.1974	.12	.0234	.20	.1922	69	1.04	10.1
220	.0332	.07	.0089	.03	.0263	72	2.61	12.7
221	.1370	.08	.0133	.14	.1319	70	.52	3.5
222	.0335	.05	.0077	.03	.0268	72	1.15	4.5
223	.1458	.08	.0162	.14	.1391	71	.09	2.2
224	.1901	.20	.0296	.10	.1813	72	1.12	5.9
225	.1780	.09	.0138	.07	.0738	124	.57	3.5
226	.1012	.23	.0240	.09	.0917	181	2.63	16.6
227	.0930	.11	.0175	.08	.0846	172	.95	4.6
228	.0580	.10	.0122	.05	.0511	147	2.14	11.8

Table 5. Plant 1E. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\bar{X}$	R	s	M_o	M_d	n	g_1	g_2
229	.3037	.43	.0937	.30	.2867	104	1.27	4.6
230	.2567	.31	.0569	.25	.2411	105	1.10	5.1
231	.0689	.11	.0144	.07	.0620	108	2.26	11.9
232	.1850	.19	.0330	.18	.1742	142	.94	3.8
233	.2214	.16	.0234	.21	.2118	141	1.90	8.8
234	.0762	.12	.0278	.075	.0683	144	6.80	66.3
235	.1414	.10	.0211	.14	.1329	92	.66	2.7
236	.1321	.16	.0192	.12	.1245	90	.48	6.4
237	.0431	.14	.0203	.14	.1344	90	3.94	20.1
238	.0600	.11	.0174	.05	.0520	90	1.26	5.6
239	.1213	.11	.0192	.12	.1137	204	1.06	4.5

Table 6. Plant 1F. Tabulation of Statistical Description of Elemental Frequency Distributions.

Identification Number	$\bar{X}$	R	s	M_o	M_d	n	g_1	g_2
240	.1871	.10	.0193	.19	.1825	95	.28	3.0
241	.1781	.16	.0237	.17	.1682	96	1.50	6.7
242	.2694	.25	.0360	.25	.2554	118	1.69	7.3
243	.1625	.16	.0345	.15	.1496	67	.53	2.5
244	.1734	.14	.0235	.17	.1682	139	1.04	4.5
245	.1769	.14	.0273	.16	.1668	72	1.13	4.3
246	.2037	.27	.0334	.20	.1923	144	3.00	15.5
247	.2032	.28	.0409	.19	.1874	111	3.08	14.8
248	.1588	.22	.0369	.15	.1456	112	2.56	10.4
249	.1319	.21	.0247	.12	.1317	96	3.90	25.2
250	.1510	.14	.0211	.15	.1438	93	1.51	7.3
251	.1348	.16	.0216	.12	.1252	94	2.81	14.6
252	.1590	.11	.0225	.15	.1506	95	2.70	14.1
253	.3511	.23	.0419	.36	.3429	94	.67	3.4
254	.1840	.11	.0190	.18	.1780	94	.89	4.6
255	.2017	.14	.0233	.19	.1997	96	1.82	7.0
256	.1116	.09	.0142	.10	.1038	96	1.02	4.3
257	.0768	.10	.0140	.08	.0709	96	1.06	5.7
258	.1651	.26	.0408	.14	.1493	116	3.03	13.2
259	.1669	.19	.0237	.16	.1564	118	3.02	16.6
260	.2799	.24	.0381	.26	.2562	116	2.10	8.5

Table 6. Plant 1F. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
261	.3509	.31	.0388	.34	.3407	116	1.16	8.0
262	.2144	.34	.0437	.19	.1940	117	2.22	10.3
263	.1242	.05	.0124	.12	.1166	113	1.16	4.0
264	.1722	.21	.0344	.16	.1576	116	2.78	11.6
265	.3021	.15	.0227	.29	.2931	119	1.50	7.0
266	.1469	.13	.0237	.13	.1473	119	1.09	4.2
267	.1405	.15	.0233	.13	.1280	117	2.13	8.0
268	.1084	.10	.0143	.10	.1005	117	1.46	6.6
269	.1276	.10	.0154	.12	.1186	178	1.09	4.3
270	.1838	.13	.0220	.17	.1741	239	1.43	5.7
271	.1411	.17	.0239	.13	.1278	120	1.86	8.8
272	.1463	.11	.0159	.04	.0485	72	1.31	5.8
273	.1594	.14	.0224	.15	.1519	168	4.43	34.5
274	.0892	.08	.0105	.09	.0833	120	.95	4.9
275	.0739	.08	.0104	.07	.0670	119	2.42	12.3
276	.0819	.24	.0349	.07	.0649	90	7.67	67.6
277	.0655	.09	.0154	.06	.0574	120	1.15	4.2
278	.1248	.14	.0308	.10	.1088	118	.48	2.4
279	.2686	.15	.0284	.25	.2616	107	.30	3.1

Table 7. Plant 2A. Tabulation of Statistical Description of Elemental Frequency Distributions.

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
280	.2443	.15	.0263	.24	.2342	197	.87	3.7
281	.1900	.14	.0239	.17	.1764	105	1.25	5.4
282	.2445	.16	.0267	.24	.2341	207	.90	3.8
283	.3567	.34	.0506	.35	.3429	122	1.18	5.7
284	.2664	.19	.0332	.25	.2539	104	1.00	3.9
285	.1056	.09	.0206	.09	.0950	46	.76	2.9
286	.0470	.06	.0092	.04	.0412	44	.95	4.8
287	.1120	.09	.0177	.10	.0950	25	.84	3.1
288	.3732	.07	.0132	.37	.0681	43	.28	3.2
289	.1472	.16	.0352	.15	.1479	55	.20	2.4
290	.1244	.17	.0285	.13	.1186	62	.51	3.8
291	.2739	.45	.1255	-	.2800	36	.33	1.8
292	.0891	.09	.0119	.09	.0836	128	.26	5.4
293	.4727	.14	.0196	.47	.4668	128	.53	4.2
294	.2879	.37	.0682	.25	.2617	57	1.24	4.7
295	.1493	.16	.0245	.14	.1375	43	2.99	14.3
296	.2707	.33	.0700	-	.2500	42	1.52	5.3
297	.1662	.11	.0244	.15	.1533	42	.88	3.1
298	.4371	.16	.0368	.45	.4292	45	.26	2.3
299	.2936	.06	.0290	.31	.3043	45	.86	2.0
300	.1819	.32	.0281	-	.8000	22	1.80	6.6

Table 7. Plant 2A. Tabulation of Statistical Description of Elemental Frequency Distributions.

(Continued)

Identification Number	$\overline{X}$	R	s	M_o	M_d	n	g_1	g_2
301	.2746	.02	.0050	.27	.2692	24	.32	1.6
302	.0521	.04	.0076	.05	.0460	24	.81	3.4
303	.4513	.28	.0837	-	.4350	23	.01	1.7
304	.2835	.18	.0393	-	.2725	23	.89	3.6
308	.3480	.33	.0773	-	.2213	21	.58	2.1
309	.1488	.11	.0221	.15	.1425	26	.91	3.8
311	.3167	.25	.0094	.31	.3030	31	.70	.9
312	.0457	.06	.0120	.04	.0342	30	.88	3.4
313	.2778	.24	.0545	.26	.2592	27	.62	3.1
314	.1911	.28	.0417	.18	.1653	121	2.37	10.5
315	.1347	.19	.0270	.12	.1239	133	2.17	10.0
316	.2005	.16	.0288	.19	.1866	132	1.38	4.7
317	.1296	.12	.0176	.13	.1229	99	1.54	7.3
318	.1450	.15	.0224	.13	.1350	110	2.33	10.6
319	.0997	.11	.0163	.09	.0924	116	1.59	6.8
320	.1299	.08	.0126	.13	.1236	89	1.04	4.9
321	.0831	.06	.0100	.08	.0765	92	1.17	4.8
322	.1259	.09	.0141	.12	.1179	117	1.36	5.4

Table 8. Coefficient of Correlation by Departments, Company 1.

Department	Mean Std. Dev.	Mean Skew	Mean Kurtosis	Skew Kurtosis
Fitting I	.314	-.161	.270	.951
Bottoming II	.258	.081	.071	.965
Make-Finish III	.725	-.236	-.192	.852

Table 9. Coefficient of Correlation for Plants.

Plant	Mean Std. Dev.	Mean Skew	Mean Kurtosis	Skew Kurtosis
1A	.483	-.668	-.284	.913
1B	.453	-.222	-.471	.960
1C	.832	-.416	-.383	.919
1D	.654	-.725	-.755	.952
1E	.779	-.329	-.246	.925
1F	.394	-.520	-.413	.953
2A	.482	-.275	-.173	.505

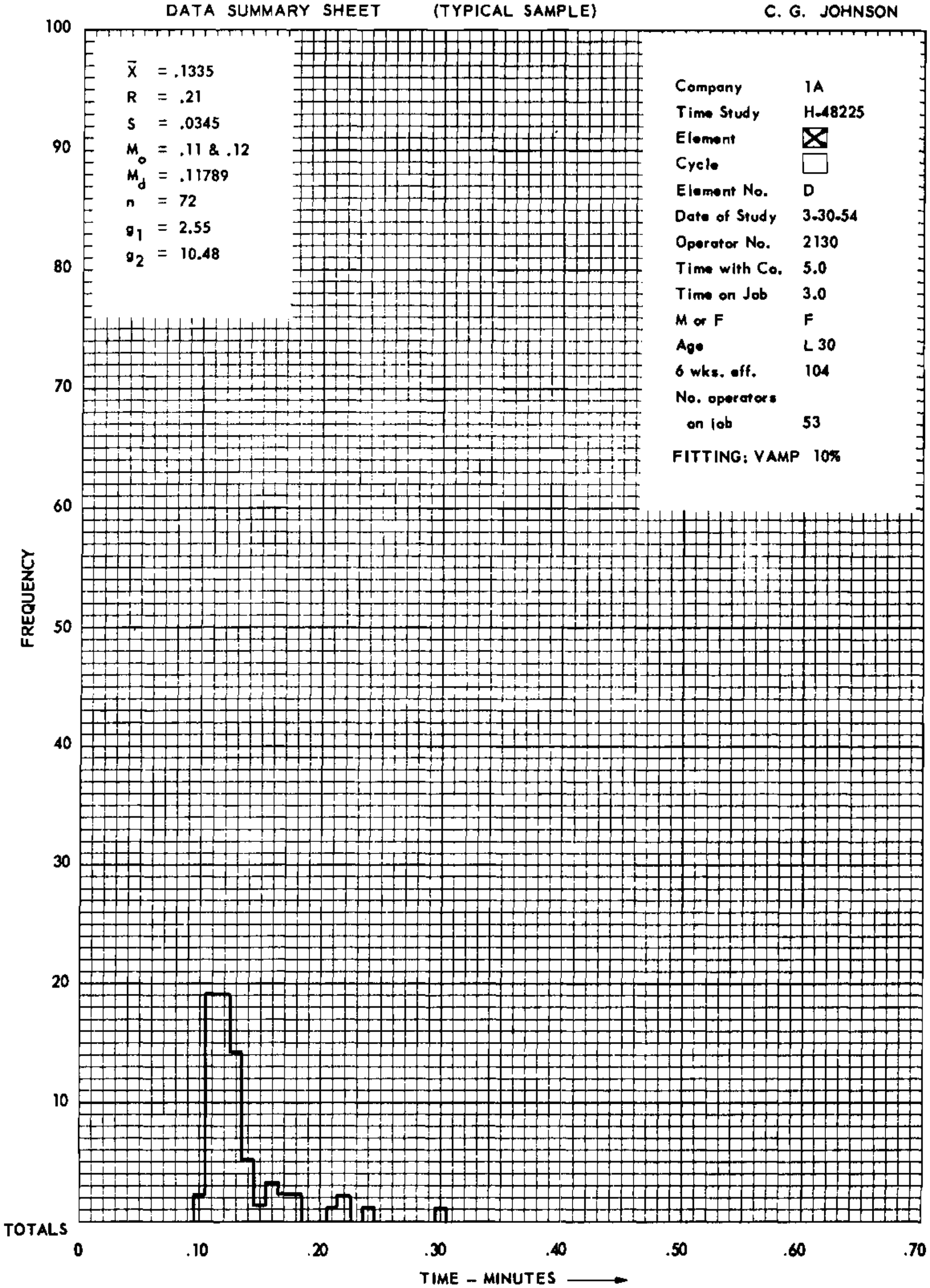

Figure 1. Element Time - Frequency Histogram.

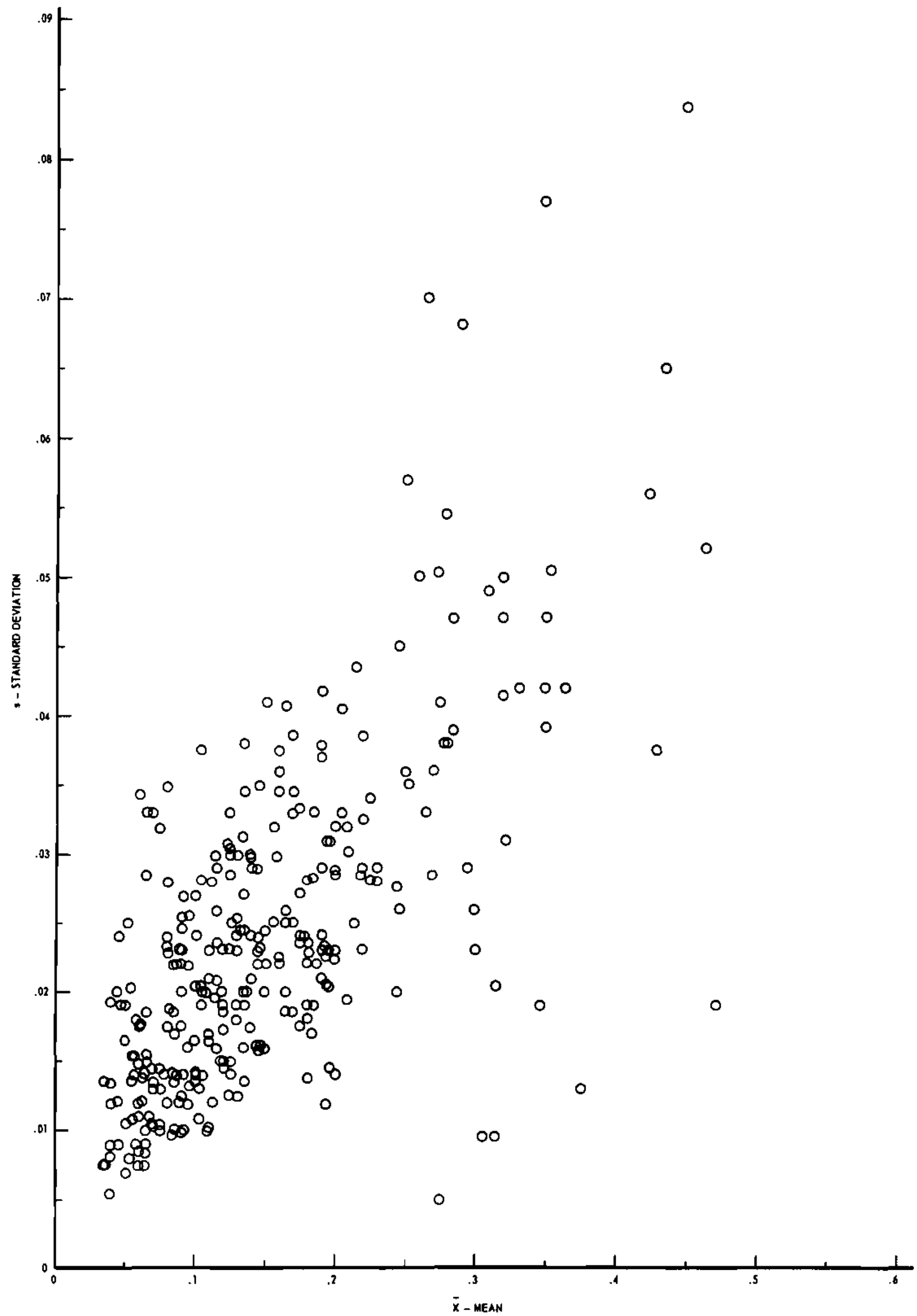

Figure 2. Plot of Statistical Characteristics of Elemental Histograms. MEAN - SKEW.

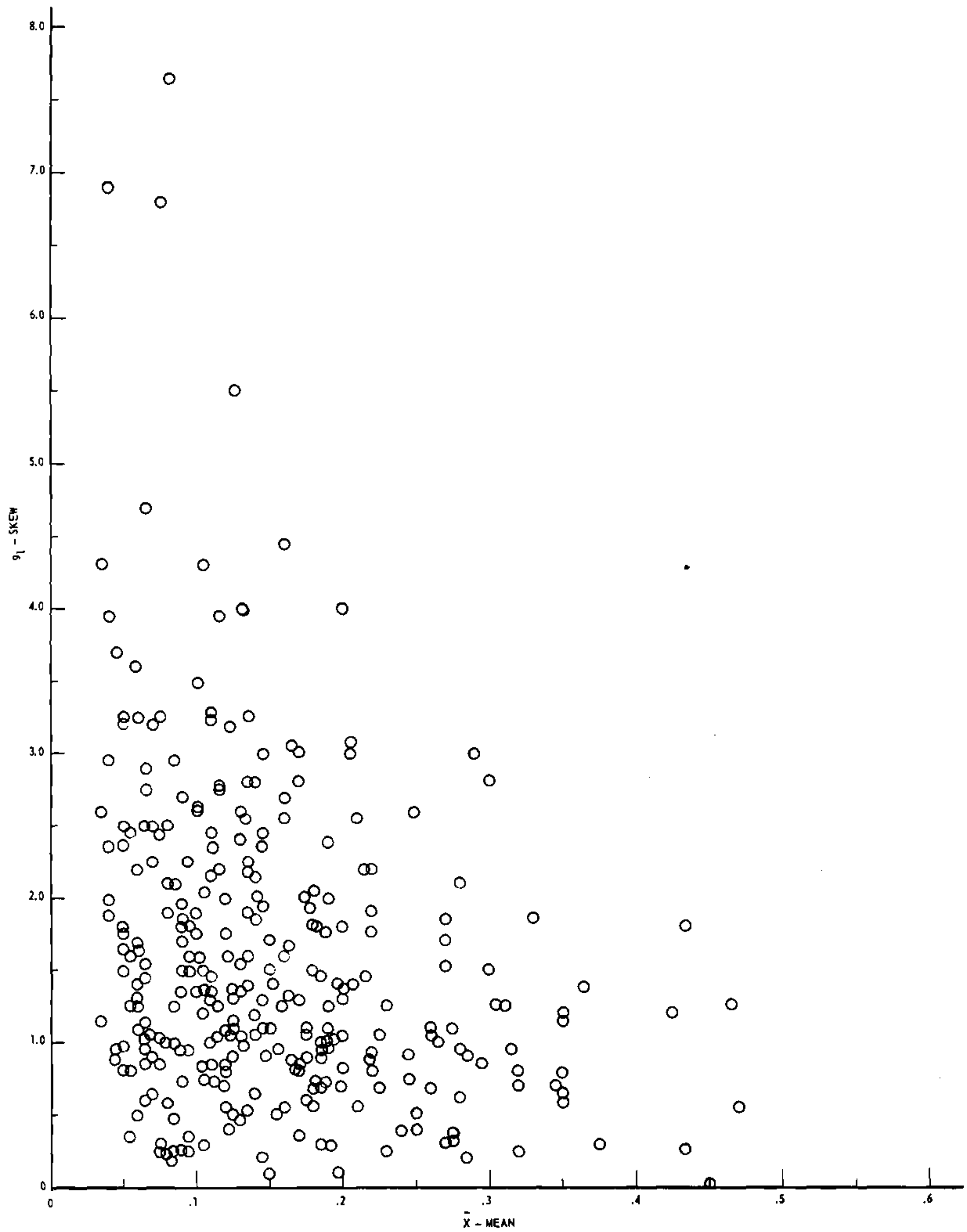

Figure 3. Plot of Statistical Characteristics of Elemental Histograms. MEAN - SKEW.

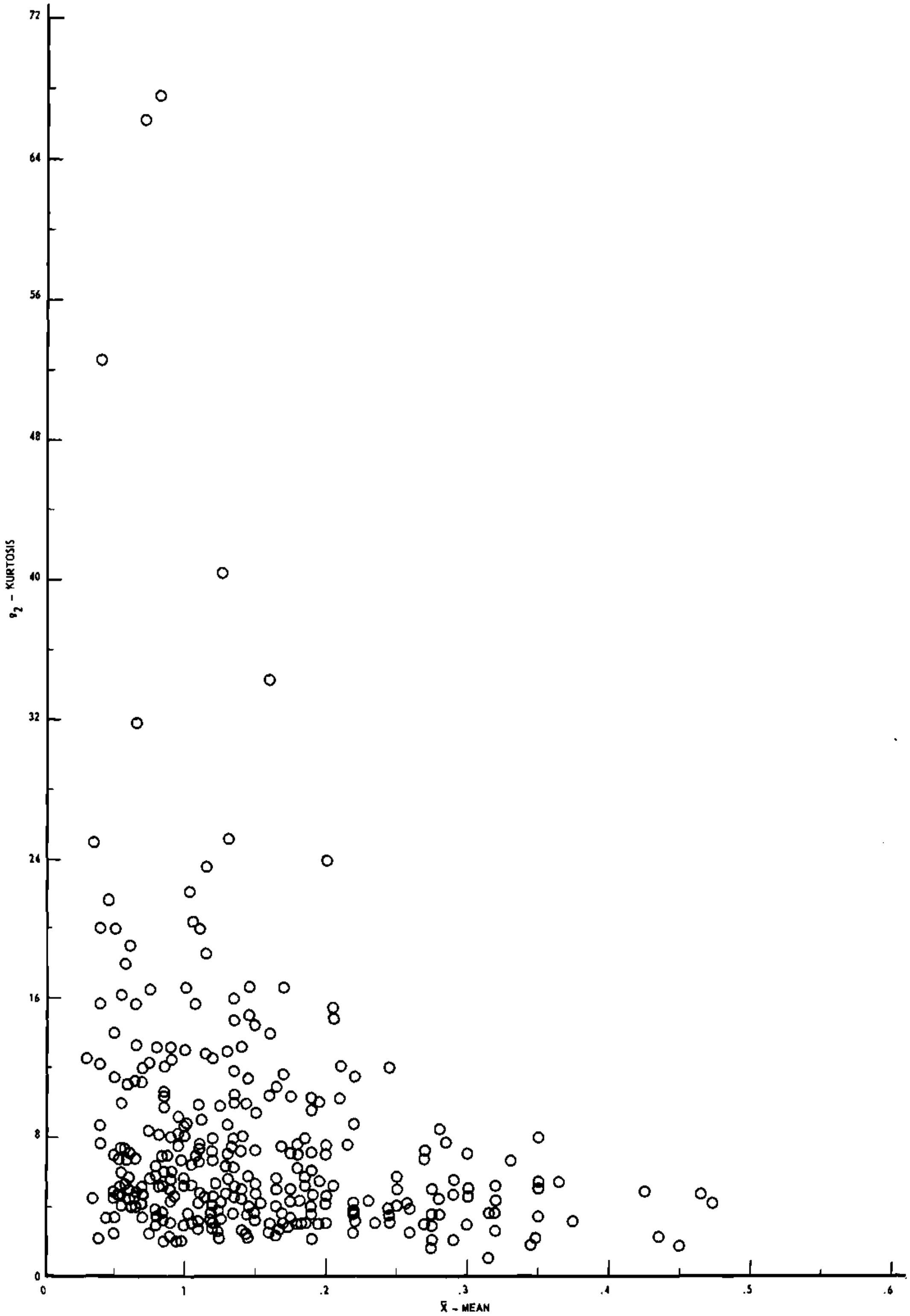

Figure 4. Plot of Statistical Characteristics of Elemental Histograms. MEAN - KURTOSIS.

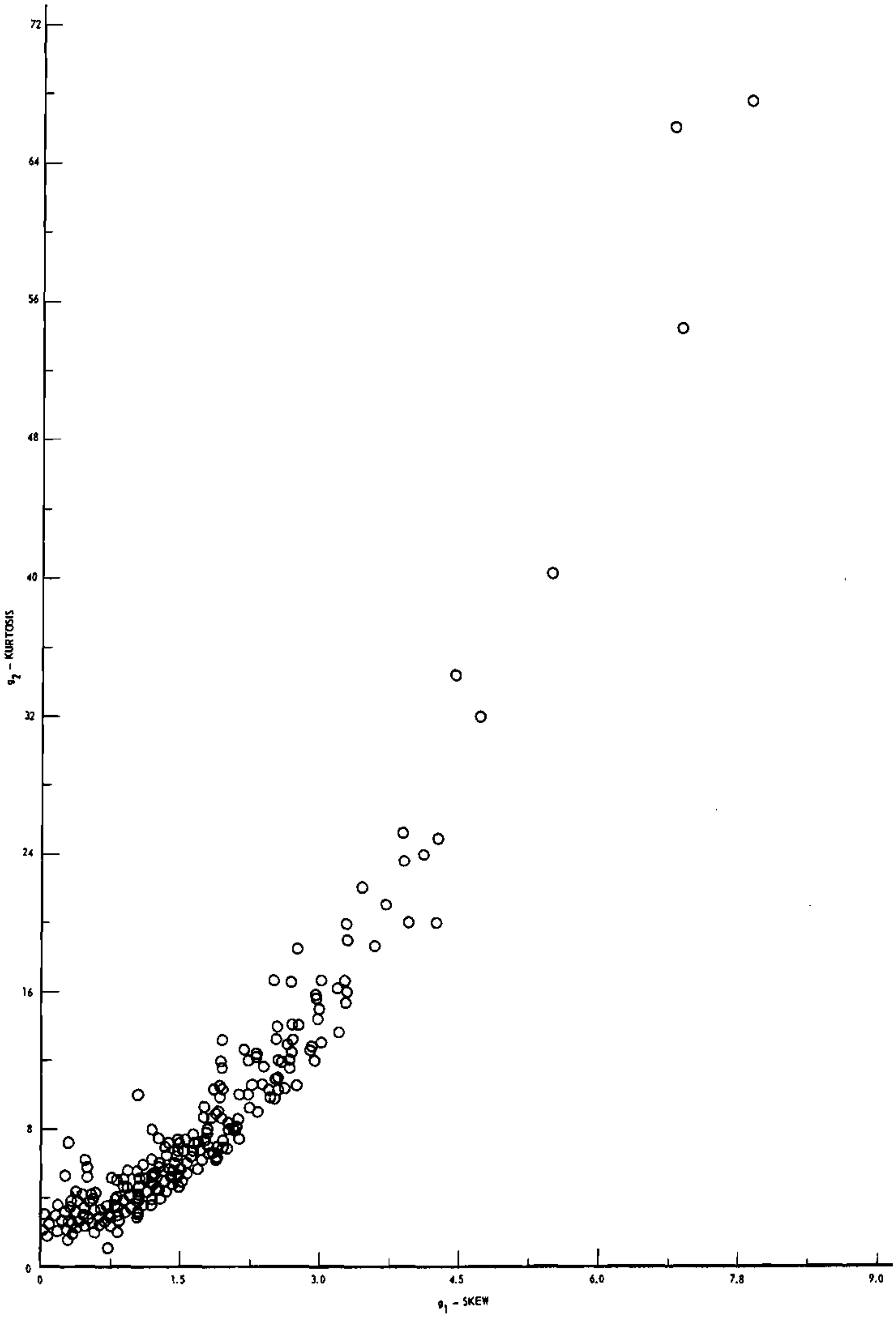

Figure 5. Plot of Statistical Characteristics of Elemental Histograms. SKEW - KURTOSIS.

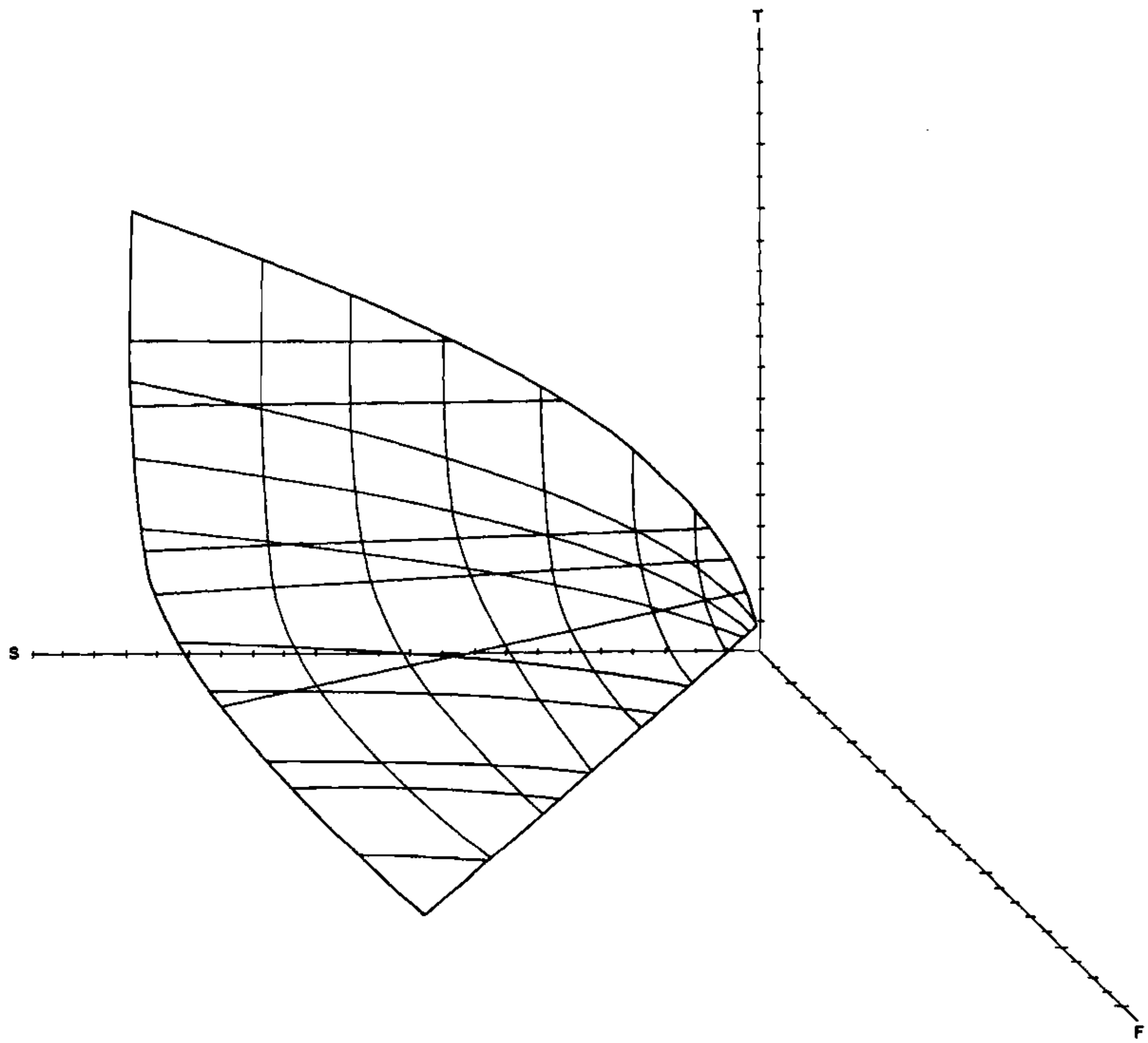

Figure 6. Pictorial View of $t^2 = \frac{K'S}{F}$.

1. MEAN $= \bar{X} = \sum_{i=1}^{k} \frac{x_i f_i}{n}$

2. RANGE $= R = x_h - x_l$

3. STANDARD DEVIATION $= s = \sqrt{\sum_{i=1}^{k} \frac{(x_i - \bar{X})^2 f_i}{n}}$

4. MODE $= M_o$ – BY SELECTION

5. MEDIAN $= M_d = L + c \frac{j}{f_m}$

6. NUMBER $= n =$ SIZE OF SAMPLE

7. SKEW $= g_1 = \frac{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{X})^3 f_i}{s^3}$

8. KURTOSIS $= g_2 = \frac{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{X})^4 f_i}{s^4}$

9. COEFFICIENT OF CORRELATION $= r \pm \sqrt{1 - \frac{s_e^2}{s_y^2}}$

Figure 7. Basic Formulas for Calculations.

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